

Extrapolating Biodiversity Values from Landscape Features

G. Chust^{1,2,3}, J. Pretus², D. Ducrot³, L. Deharveng⁴

¹*Institut d'Estudis Espacials de Catalunya
Edif. Nexus
Gran Capità 2-4
08034 Barcelona
Spain*

²*Departament d'Ecologia
Facultat de Biologia (Universitat de Barcelona)
Diagonal 645
08028 Barcelona
Spain*

³*Centre d'Etudes Spatiales de la Biosphère (CNES-CNRS-UPS)
18, Avenue Edouard Belin
31055 Toulouse Cedex
France*

⁴*Laboratoire d'Ecologie Terrestre (UMR 5552 du CNRS)
118 route de Narbonne
F-31062 Toulouse cedex 4
France*

There is an increasing interest in testing the reliability of biodiversity assessment by satellite images (Stoms and Estes 1993, Innes and Koch 1998, Cardillo *et al.* 1999, Nagendra and Gadgil 1999). Spectral information, for instance, can predict the occurrence of plant, butterfly and bird species (Debinski *et al.* 1999). A landscape diversity index derived from satellite imagery explained 50 % of bird species richness (Jørgensen and Nøhr 1996). Species habitat characterisation by spectral classification and posterior landscape spatial analysis constitutes the link between the information acquired from space and community structure. However, such a potential use of remote sensing is considered as very limited by Gulinck *et al.* (2000). The objective of this paper is to demonstrate remote sensing capabilities for mapping species richness and endemism of Pyrenean soil fauna.

The Massif of Arize comprises mountains of moderate elevation (maximum 1715 m above sea level) located in the Northern part of the French Pyrenees. Natural vegetation comprises beech forests (*Fagus sylvatica*), above 1000 m, and mixed woods of several other deciduous species dominated by oaks, below 1000 m. Pastures, agricultural land and small villages surround natural forests and stands of exotic coniferous introduced in the Massif.

Collembola were sampled in 27 stations during 1998, with sites ranging from 400 m to 1400 m in elevation. The stations were located in two forest habitats:

beech and oak forests. The oak wood comprises also other deciduous species (*e.g.*, chestnut, birch, *Robinia pseudoacacia*). The soil fauna was obtained within 7 to 10 days, using Berlese-Tullgren devices. Taxonomic identification of Collembola was at the species level. Two ecological variables were selected: species richness and the number of endemic species (*i.e.*, those species endemic to the Pyrenees or to a part of the Pyrenees).

A high-resolution optical image covering the area of the test site was used, based on that acquired on 13th of July in 1990 by Landsat Thematic Mapper (TM) satellite. The resolution of TM images is of 30 m by 30 m. Two types of thematic information were derived from satellite images: vegetation indices and a land cover classification. Infrared and red bands were used to derive the Normalised Difference Vegetation Index (NDVI) and the Leaf Water Content Index (LWCI). NDVI and LWCI give a measure of the photosynthetic active biomass and leaf water content, respectively. The advantage of those vegetation indices is that they mitigate the effect of shadows in radiometric response. Land cover data was previously derived by means of a supervised classification into 12 categories with a global accuracy of 90.1 %. The classification was performed with the maximum likelihood procedure, using spectral bands and ancillary data (digital elevation model and shaded relief model).

Spatial indices were performed over the thematic maps for a square window centred in the sample station. We calculated 5 spatial indices on the NDVI and LWCI maps: *Mean*; *Standard Deviation* (SD), as a measure of heterogeneity; *Angular Second Moment* (ASM), as a measure of spatial homogeneity; *Mean Distance* (MD), it is a measure of the difference between the mean of vegetation indices values, corresponding to the land cover of the sample station, and the vegetation indices values of the window; and *Mean Distance of Central Pixel*. We calculated 3 other spatial indices over the land cover classification: *Forest Land Cover Proportion*; *Land Cover Proportion of Central Pixel*; and *Number of forest patches*.

We tested the relationship between entomological data and landscape descriptors by stepwise multiple linear regression for each window size. The optimal scales, i.e. those with maximal multiple correlation of coefficient (R^2), were selected to map the soil fauna diversity by determining the collinearity of scales. Topographic variables and spatial trends (coordinates of x, y, xy, x^2, y^2) were introduced to improve the final model.

The species richness is correlated with spatial indices at the lowest scales, up to 900 m side (Fig. 1a), the curve is slightly erratic presenting a maximum value at 750 m side. This maximum corresponds to the unique optimal scale explaining a 64.7 % of total variance (Fig. 2a). The model involves a positive dependence on SD(NDVI) and a negative on SD(LWCI), ASM(LWCI) and MD(LWCI).

The number of endemic species is highly correlated with spatial indices at any scale, except in 90 m side (Fig. 1b). The collinearity analysis reveals that scales of 330 m X 330 m and 1590 m X 1590 m are optimal. When topographical and space variables are introduced, the final model involves only the first scale and elevation, together explaining 78.3 % of variance (Fig. 2b). Endemicity depends positively on elevation and patch number, and negatively on SD(LWCI).

Satellite data did provide information on the landscape pattern that partially explained important biotic parameters of Collembola assemblages, such as species richness and the degree of endemism. Remote sensing and digital elevation models are able to produce a reliable map of endemic Collembola by means of a scalar analysis. The method described above may be seen as a 3-step approach: first, setting spatial patterns from satellite images; second, linking spatial patterns to biodiversity measured at a limited

number of points; third, extrapolating biodiversity values to the whole area under study. Implicit assumptions of the model are (i) that it may only apply in an homogeneous faunistic unit where the same habitat can be potentially colonized by the same species pool; (ii) that species do not spread freely into an ecological unit (the model is thus not operational or less operational for aquatic habitats).

It is possible that satellite data may provide insight into the subterranean fauna as well. For example, some of the characteristics of Landsat images may reflect underlying geological features that in turn may have a major impact on both the cave and interstitial fauna. It is even possible that measures of vegetation *per se* may directly influence the subterranean fauna. In nearly all subterranean communities, food is the result of infiltration from the surface rather than chemoautotrophy. Measures of vegetative cover and quality are measures of productivity of the surface environment, which may be a relative measure of the amount of food ultimately entering the subsurface environment. In fact, the most serious limitation of the method is the low and pre-defined number of access to subterranean habitats, especially in karstic areas. Where sampling can be done at a reasonable density, predicting patterns of biodiversity using this kind of model certainly deserves consideration.

The analysis of scale presented here may also be directly applicable to subterranean biodiversity. The question of the area of influence the surface has in determining subterranean biodiversity is also an interesting question, as it is for the soil fauna. Christman and Culver (2001) touch on this very question of the effect of scale when they investigated whether the number of caves in adjoining counties had an impact on the number of species in the county. Unlike the soil case where optimal scales were on the order of hundreds of meters, in the case of caves the optimal scale may be on the order of tens of kilometres. Both cases could be analysed using identical techniques.

Such spatial models could be used for designating areas with high biological diversity and not yet protected, namely *hotspots*. The *gap analysis*, or hotspot identification process, is a critical step to design environmental protection strategies with scientific criteria. In less populous or under developed regions, for instance, there is a case for predictive modelling in an attempt to identify sites which might be important for soil and subterranean fauna. In those cases, biodiversity mapping by sampling over the entire area at reasonable resolution, e.g. 1 km, is not feasible.

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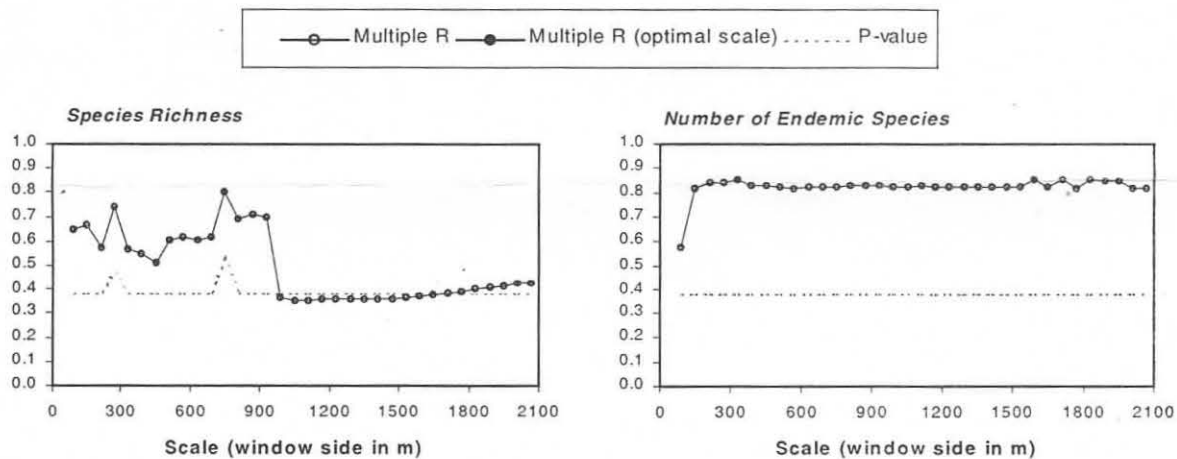


Figure 1. Species Richness and Number of Endemic Species response on landscape descriptors at different spatial scales.

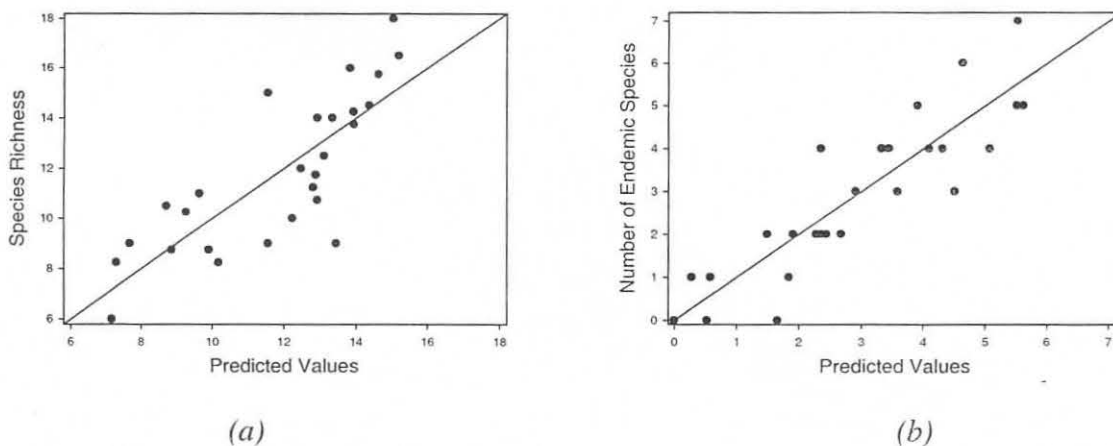


Figure 2. Predicted values of final multiple regression models against Species Richness (a) and the Number of Endemic Species (b).